Argonne NATIONAL LABORATORY

Developing an improved climate emulator for use in energy policy and economic analysis

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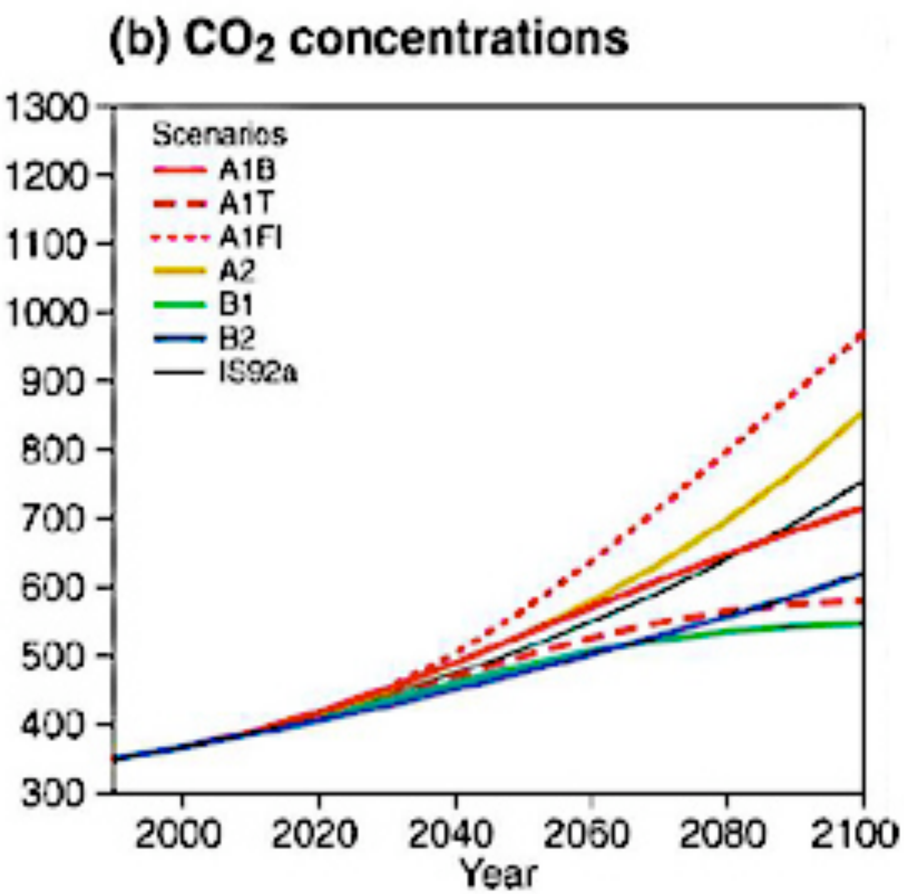
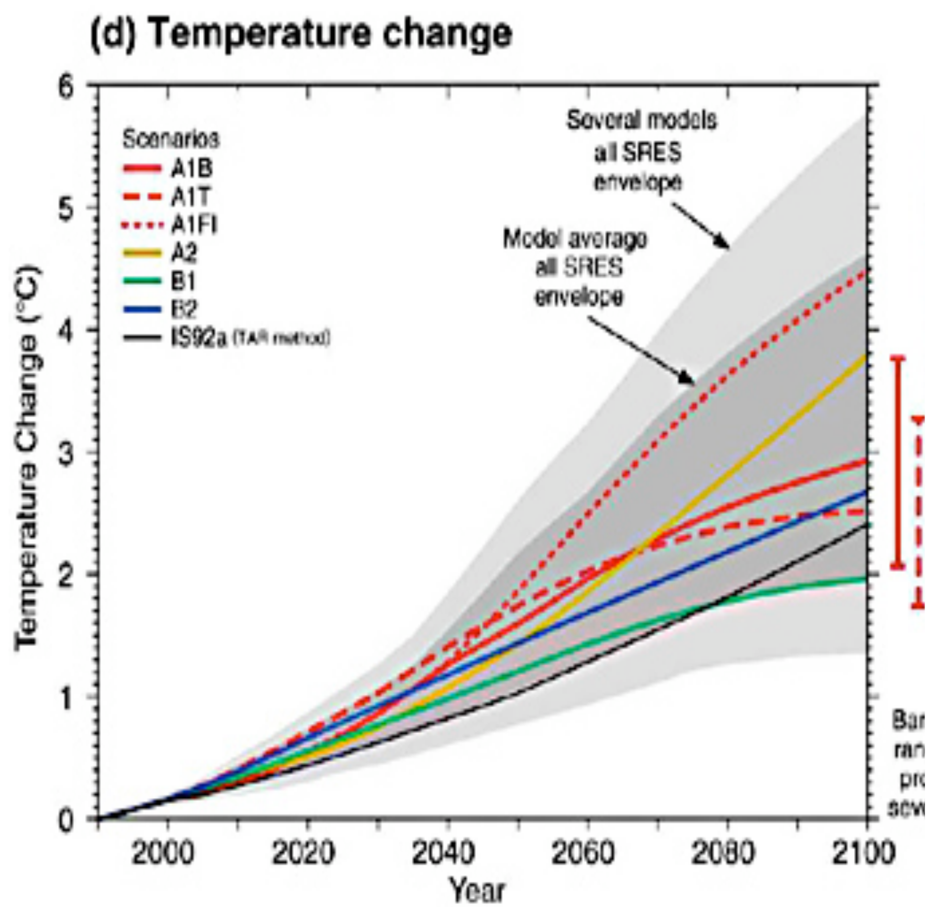
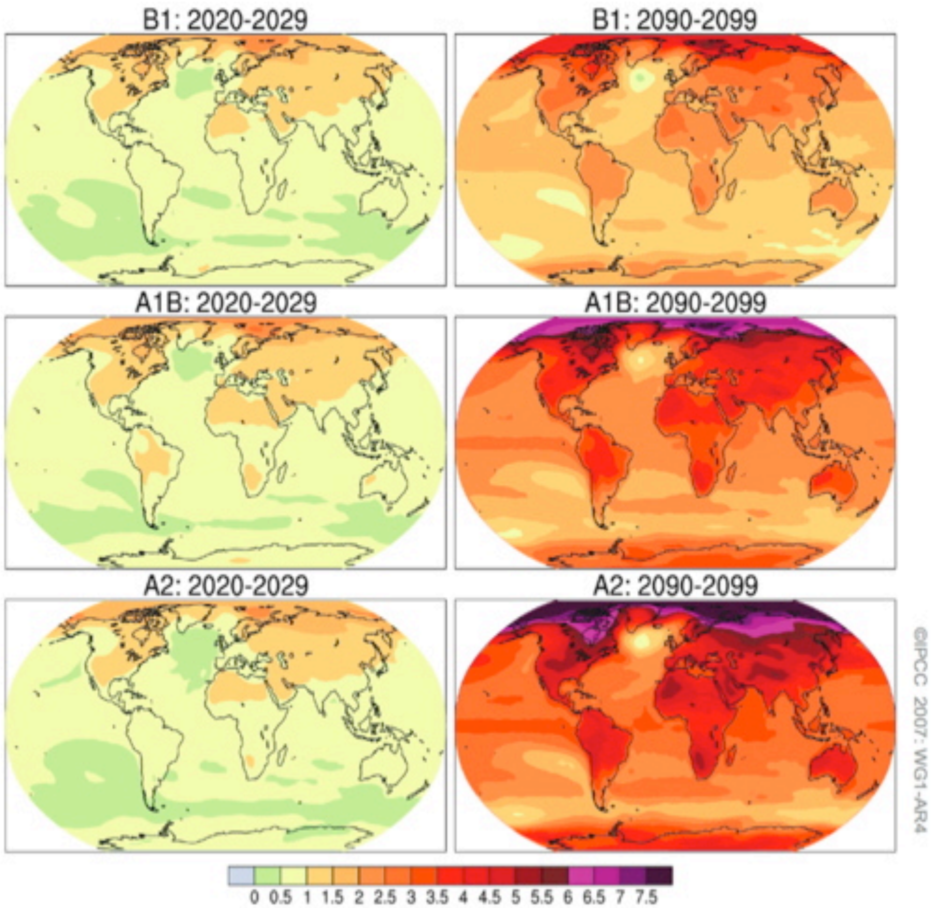
Changes in atmospheric CO_2 concentration lead to changes in global average temperature



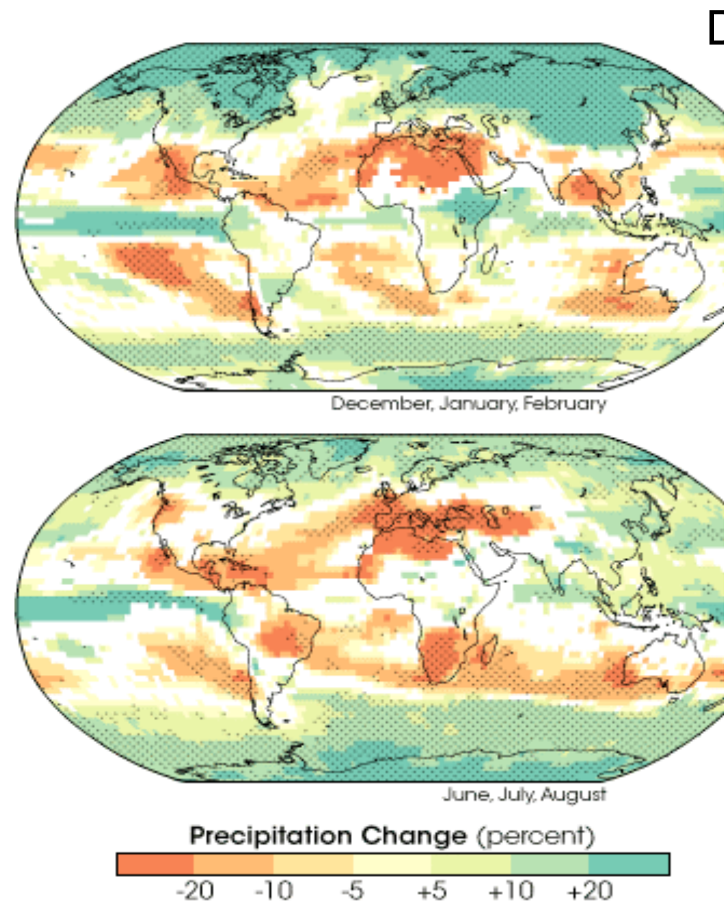


(IPCC, 2001

There are also changes in regional climate



Multi-model average temperature change (relative to 1980-1999)



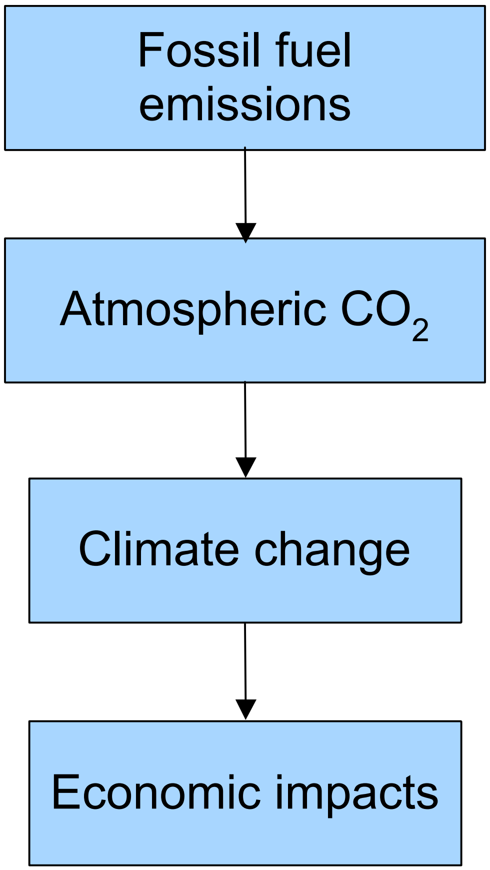
Precipitation change in 2100 for sresa1b (relative to 1980-1999)

(IPCC, 20

What are the human-scale impacts of climate change?

Ian Waldie, Getty Images

Integrated Assessment Models attempt to calculate the effect on human economies

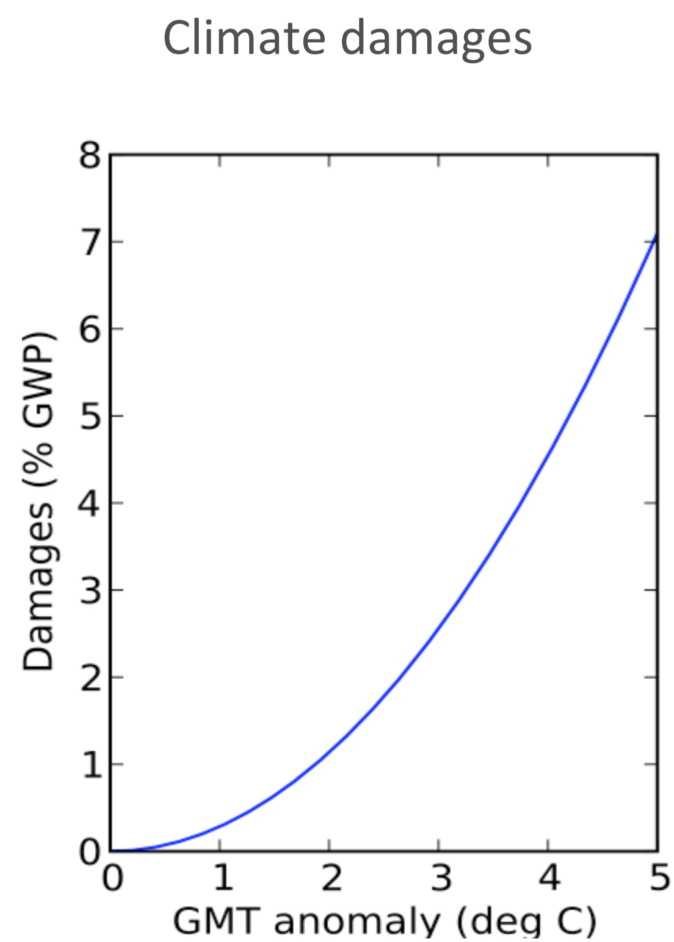


Cutting GHG emissions reduces impacts

- Determine outcome of single policy choice, or estimate optimal trade-off between GHG abatement and climate induced economic damages
- Both cases require multiple iterations
- Detailed Computational General Equilibrium (CGE) economic models are iterated solutions to optimize utility of consumption.
- Optimization methods can require 10^6-10^8 runs of the IAM

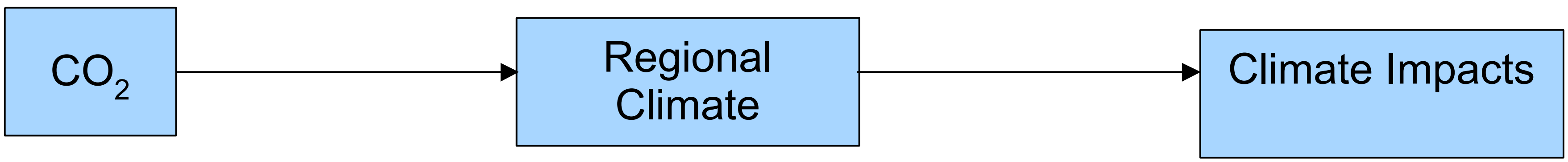
Climate damages are often estimated crudely and ad h

Example: Yale's DICE model – all climate effects parameterized by parabolic function with global mean temperature. Climate model is *emulated* by a handful of simple equations.



Why use emulation? To expensive to run GCM inside an IAM

Need better estimates of damage at *regional* scale



This will require not only improved economic models but improved regional climate forecasts, connected to economic model in computationally tractable manner.

Need better estimates of damage at regional scale

CO_2 → Regional Climate → Climate Impacts

Current approach is too simplistic:
assumes **climate trajectory does not matter**

MAGIC/SCENGEN Approach: For a given forcing scenario

- global mean temperature (GMT) is calculated using MAGICC
- regional climate is scaled linearly with GMT

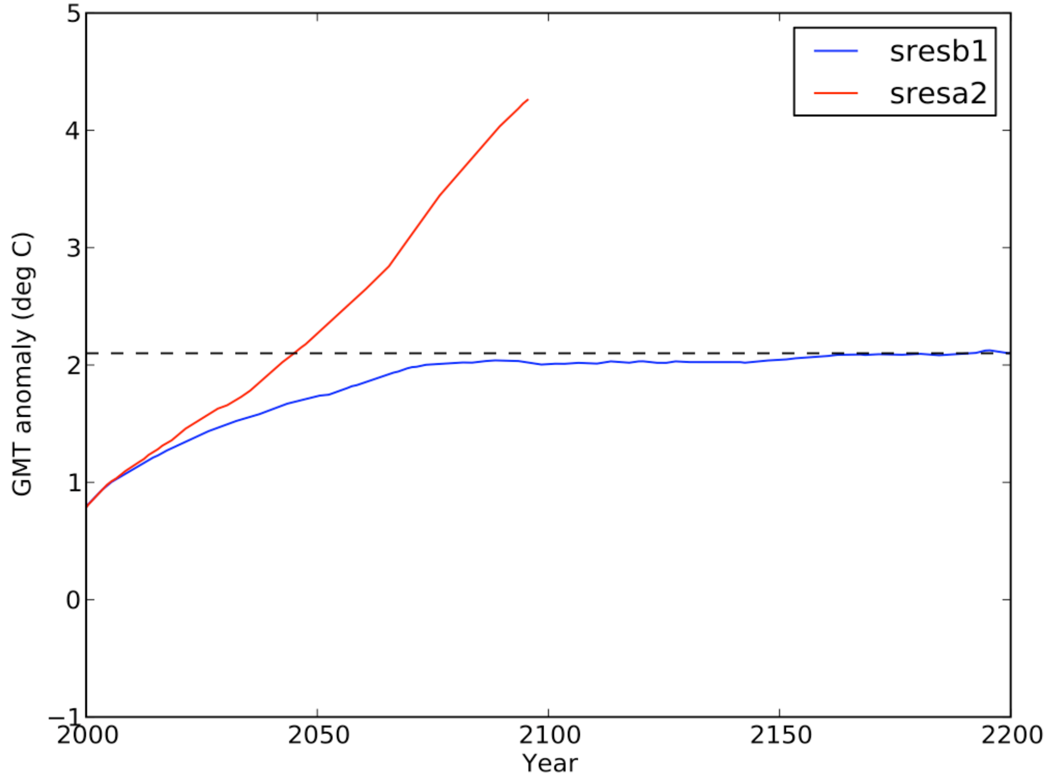
  $\text{Temp(Milan,2100)} = K_{Temp}\text{(Milan)*GMT(2100)}$

  $\text{Precip(NSW,2100)} = K_{Precip}\text{(NSW)*GMT(2100)}$

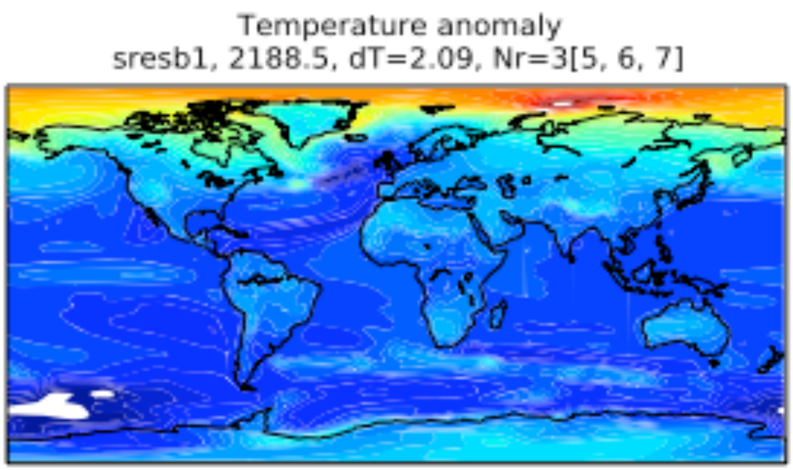
$CO_2 \xrightarrow{\text{MAGICC}}$ Global Mean Temperature $\xrightarrow{\text{Linear pattern scaling}}$ Regional Climate

Same GMT can be reached by very different paths:

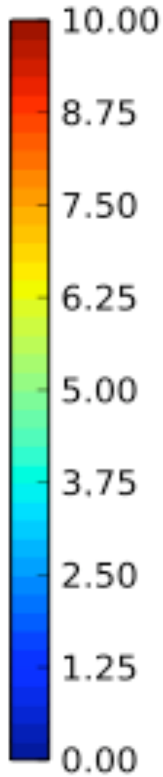
- CCSM output for SRESB1 and SRESA2
- Consider two times when GMT is same

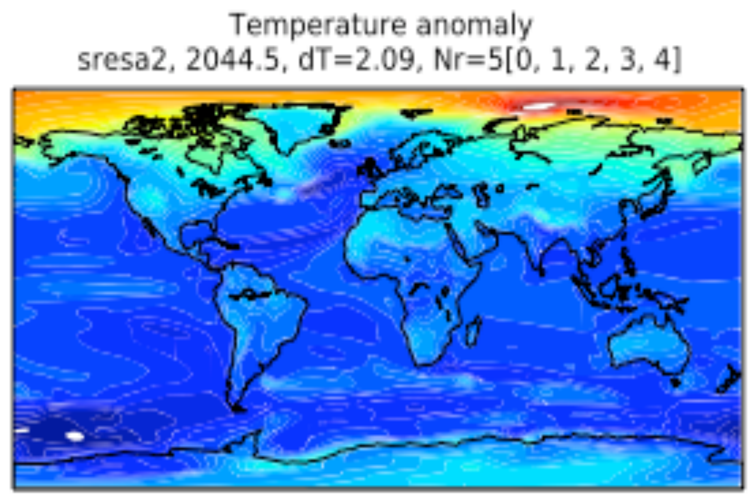


Does trajectory matter?



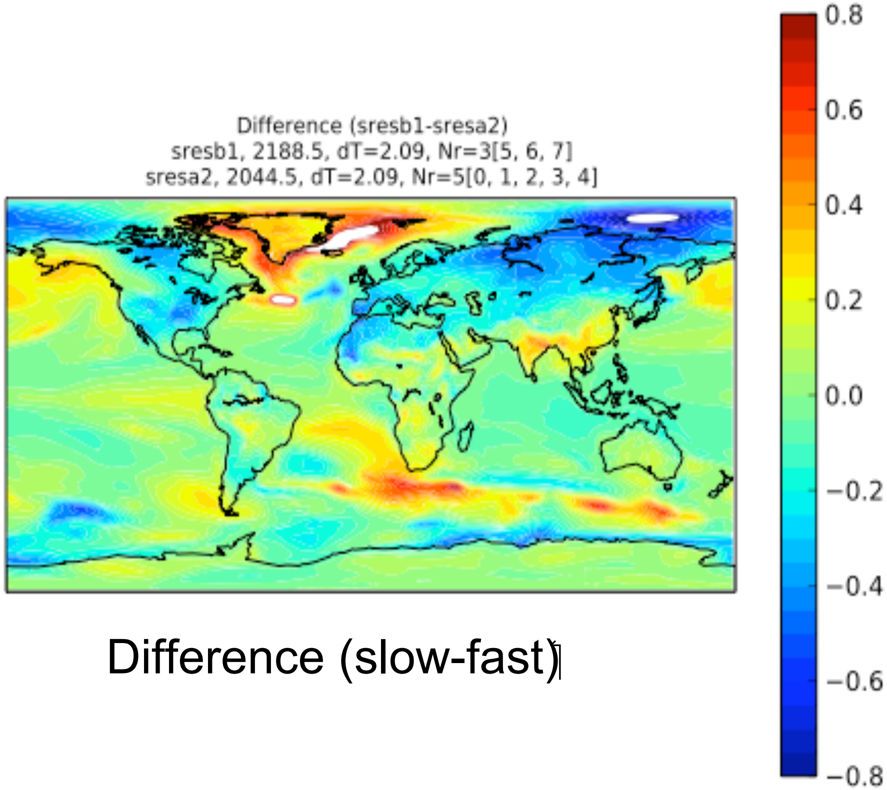
SRESB1 in 2185



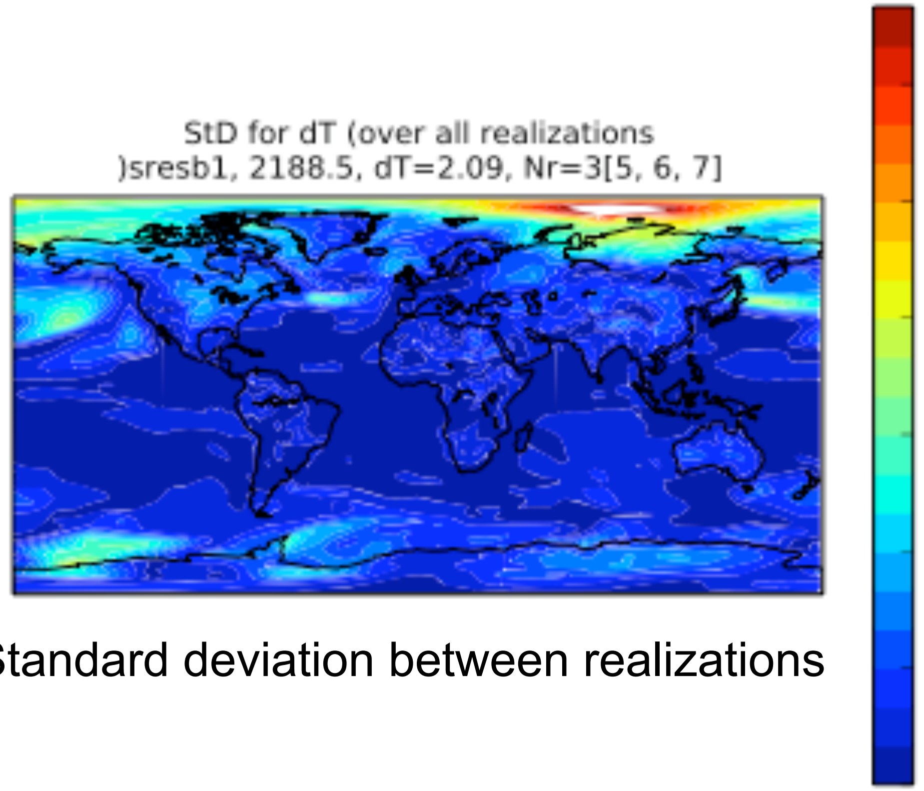


SRESA2 in 2045

Does trajectory matter?

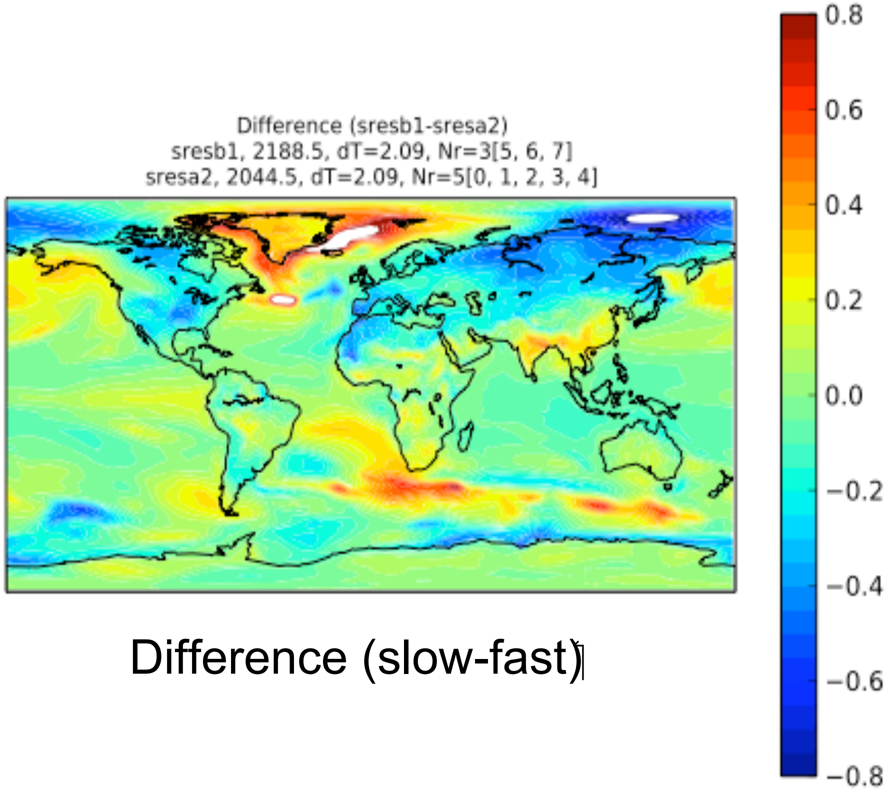


Difference (slow-fast)

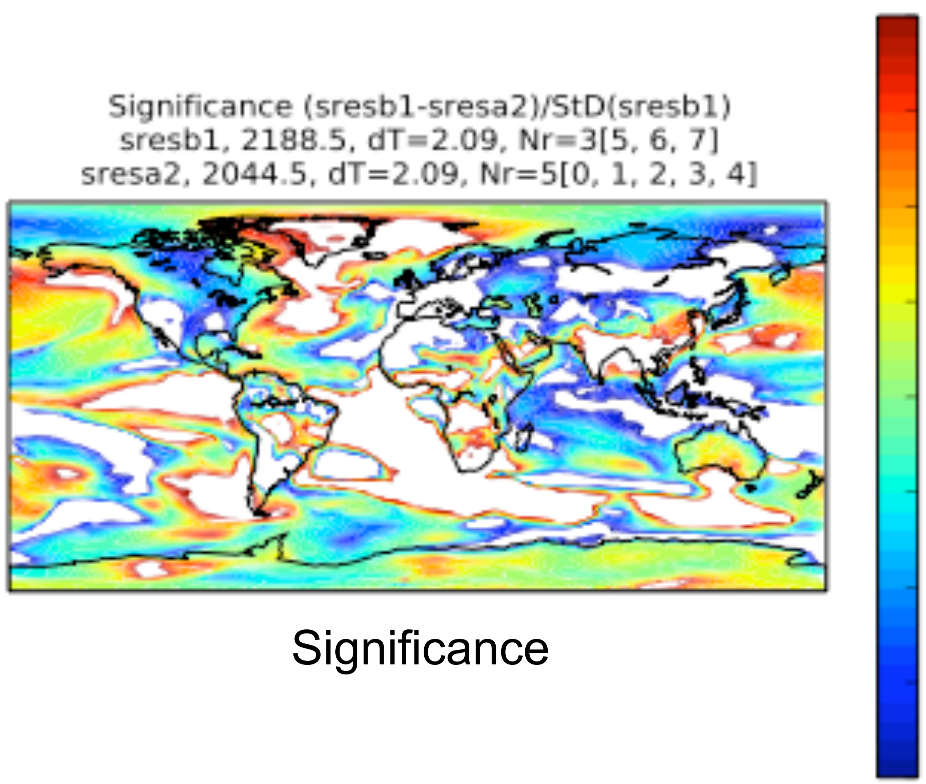


Standard deviation between realizations

Does trajectory matter?



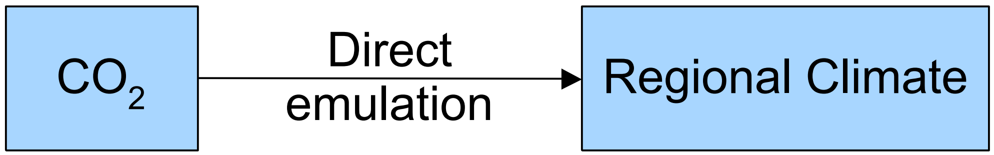
Difference (slow-fast)



Significance

Yes it does

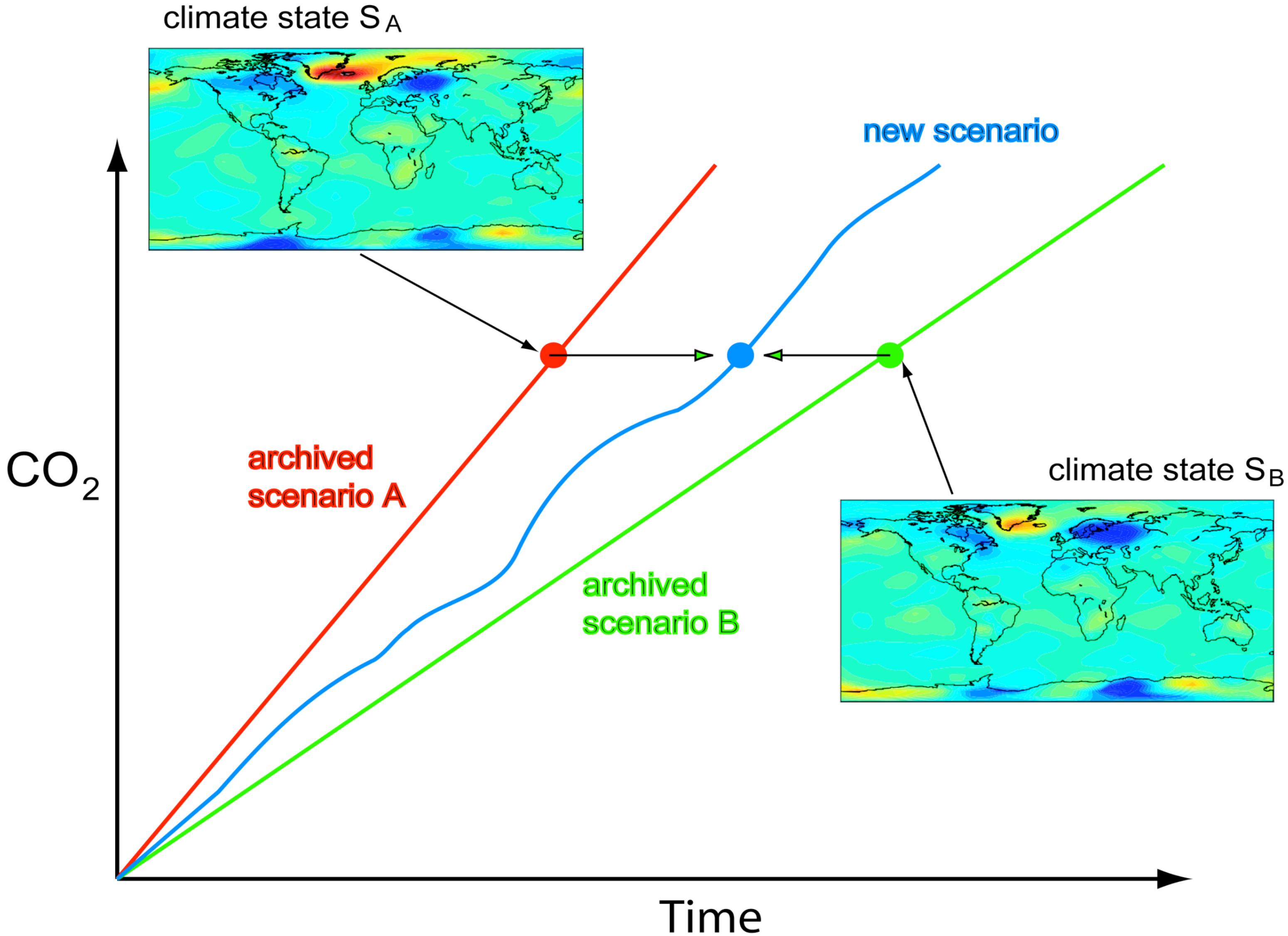
Need a more direct approach



Consider three alternative techniques for climate emulation

- Interpolate between nearest neighbors
- Implement a pattern scaling variant that allows nonlinear scaling of climate with CO_2 concentration and growth rate
- Use principal component analysis tools to construct a series of output surfaces for each variable

Climate interpolation



Climate Interpolation

- Generate a library of CCSM runs corresponding to differen
CO_2 scenarios
- Produce an emulator for approximating CCSM output for a
arbitrary CO_2 scenario
- Incorporate this emulator in an Integrated Assessment Model

Problem: CCSM takes a long time to run!

- Even with low resolution, library of runs would require 800,000 CPU hours, and month
of wall time

FOAM library and emulator

- Fast Ocean Atmosphere Model
- R15 resolution (4.5° lat x 7.5° long) in atmosphere

- Procedure
  - Store surface temperature, precipitation, solar radiation, etc every 3 hours
  - Store other variables every month
  - Use slab ocean, but increase mix layer depth to increase time it takes ocean to warm
  - Emulate temperature, precipitation, growing season, drought, floods, heating and cooling degree days

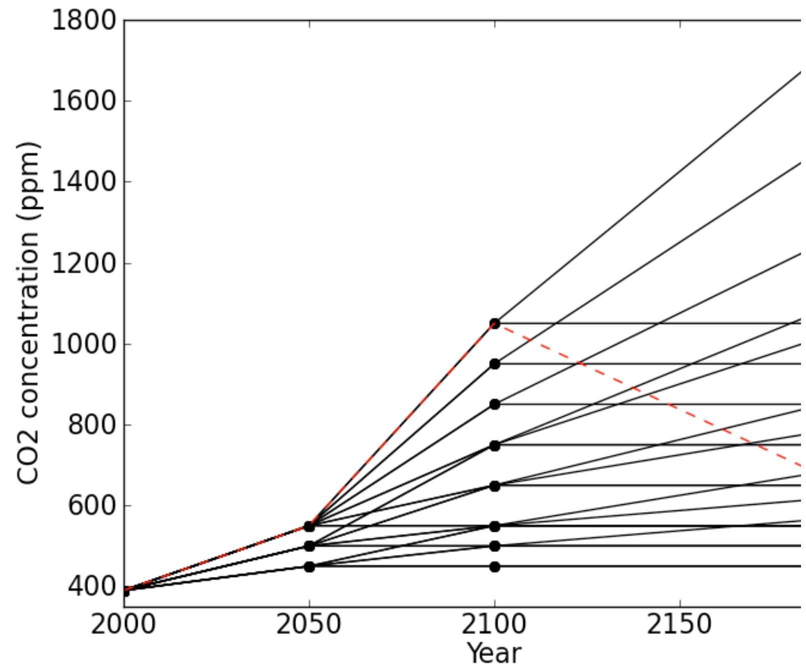
Building FOAM library for emulation

Compared with CMIP3

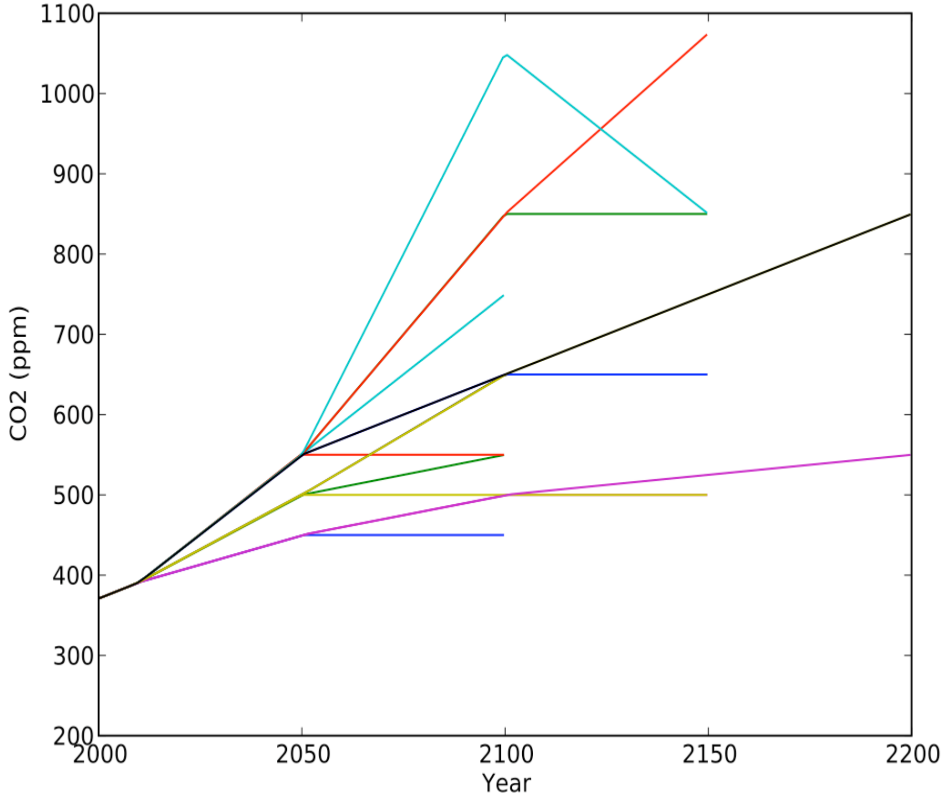
- Consider more scenarios
- More realizations of each scenario
- Simulate beyond 2100 to 2200
- Keep other forcing constant to isolate effects of CO_2

Tree design

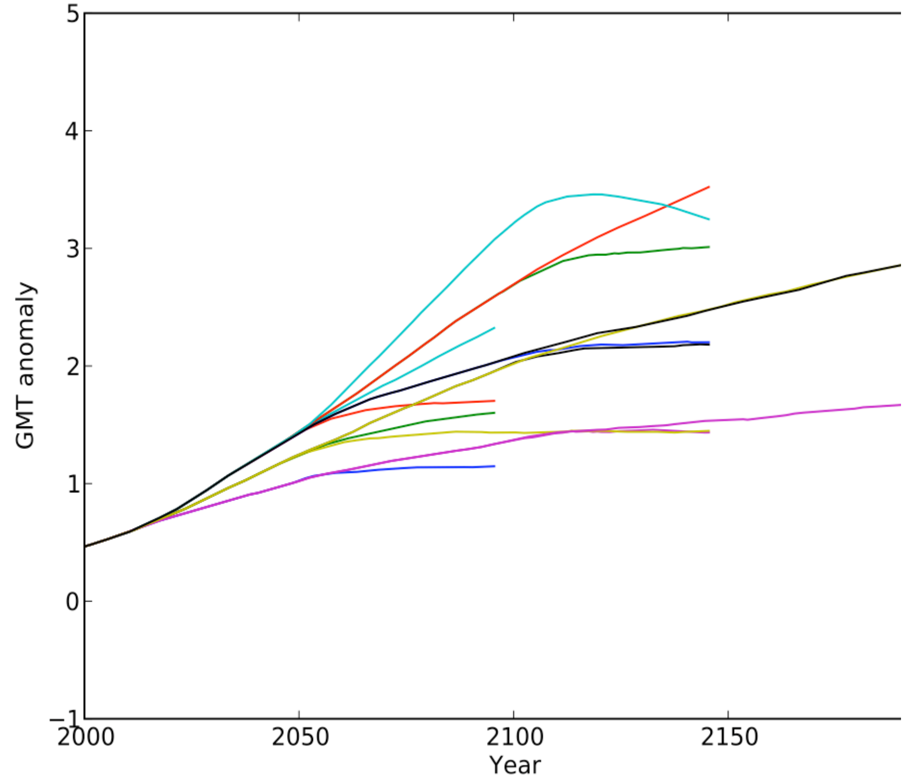
- Saves computing time
- Allows hysteresis in climate to be examined



FOAM library

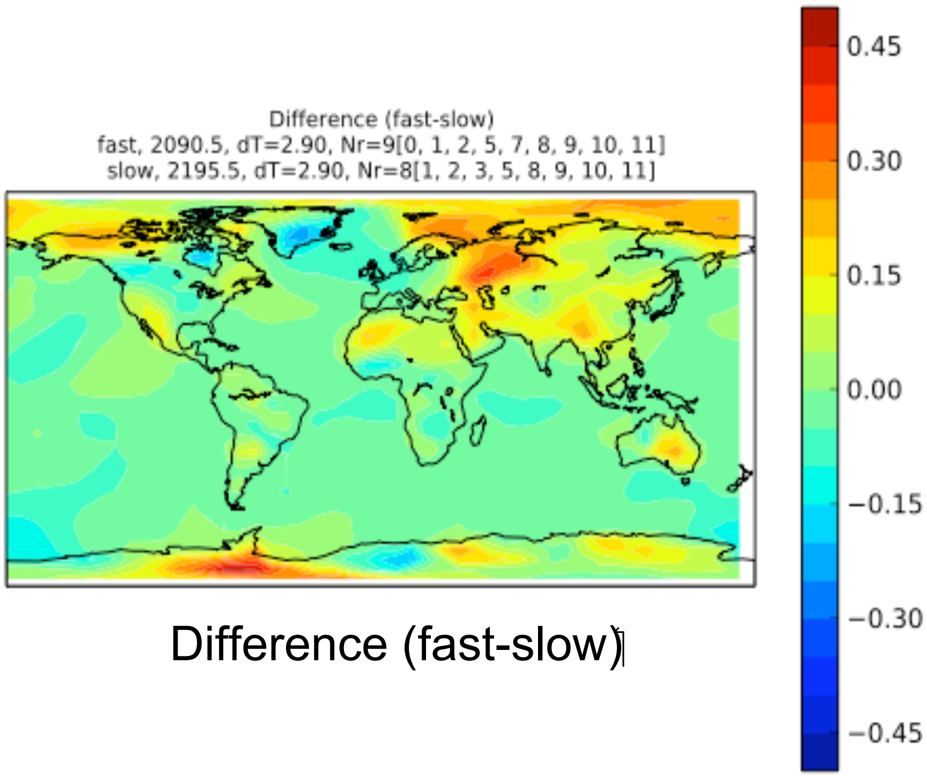


CO2 scenarios

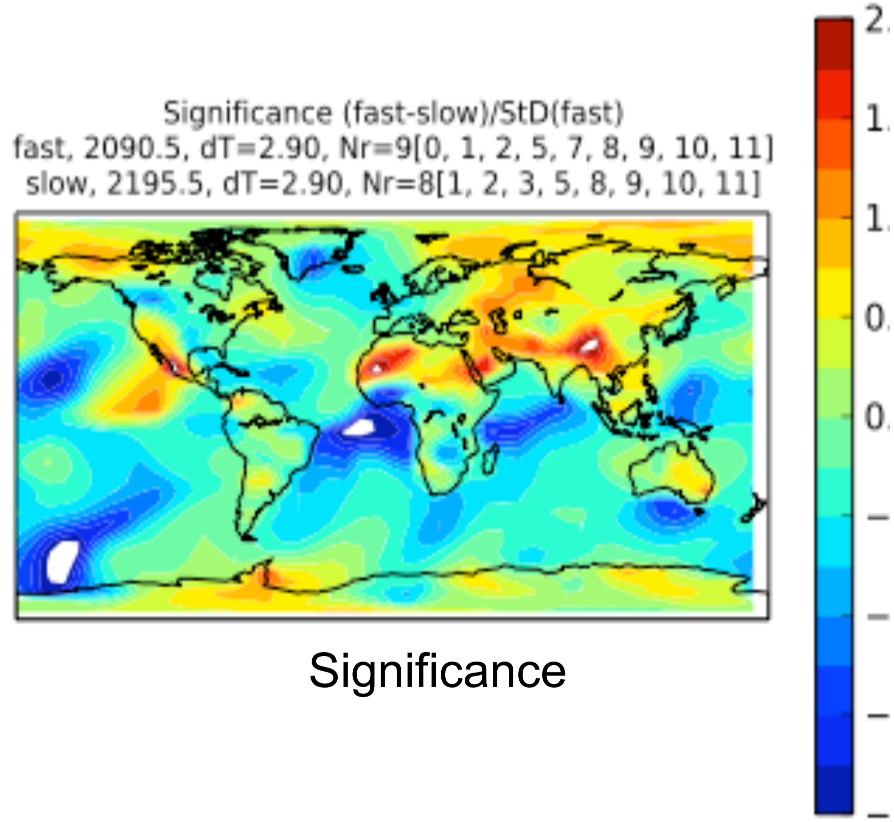


Global mean temperature anomaly

Results from FOAM library.



Difference (fast-slow)



Significance

Trajectory dependence not as strong

Should we have used FOAM with a slab ocean?

- Trajectory does not matter as much as expected
- Realization variations swamp any variation due to trajecto
- Slab ocean, even with increased mixed layer, failed to capture important ocean dynamics

Current work: examination of pattern scaling issue

- FOAM library shows limited trajectory dependence but can be used for fundamental research on regional climate patterns

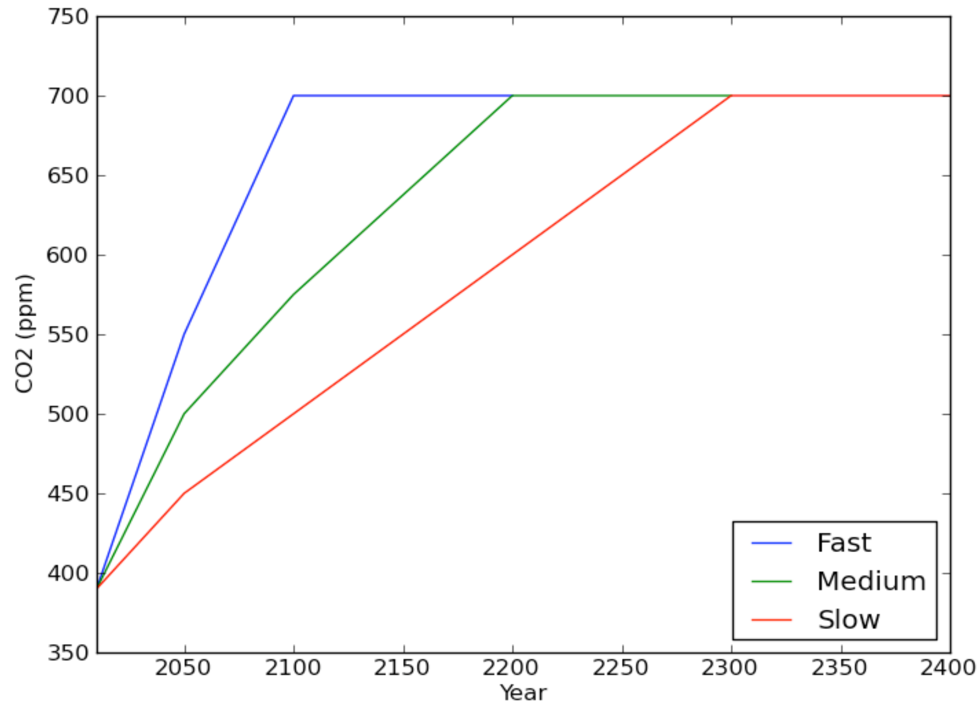
- Task 1: Examine viability of linear pattern scaling for inherently non-linear variables
  - Use 3 hourly data from FOAM library to determine agricultural and economic relevant climate variables (drought index, growing season length, cooling degree days). Expect linear pattern scaling to fail, since these variables are nonlinear by design
  - Examine whether nonlinear variant on pattern scaling works

- Task 2: Examine viability of pattern scaling at all for precipitation
  - Greater variation in precipitation than T may mean no significant pattern that rises above realization dependence noise.

Current Work: expanding to full GCM

Part way through (60%) completing a prototype library of CCSM3 runs with

- 3 scenarios
- 5 realizations
- Low resolution (T31)

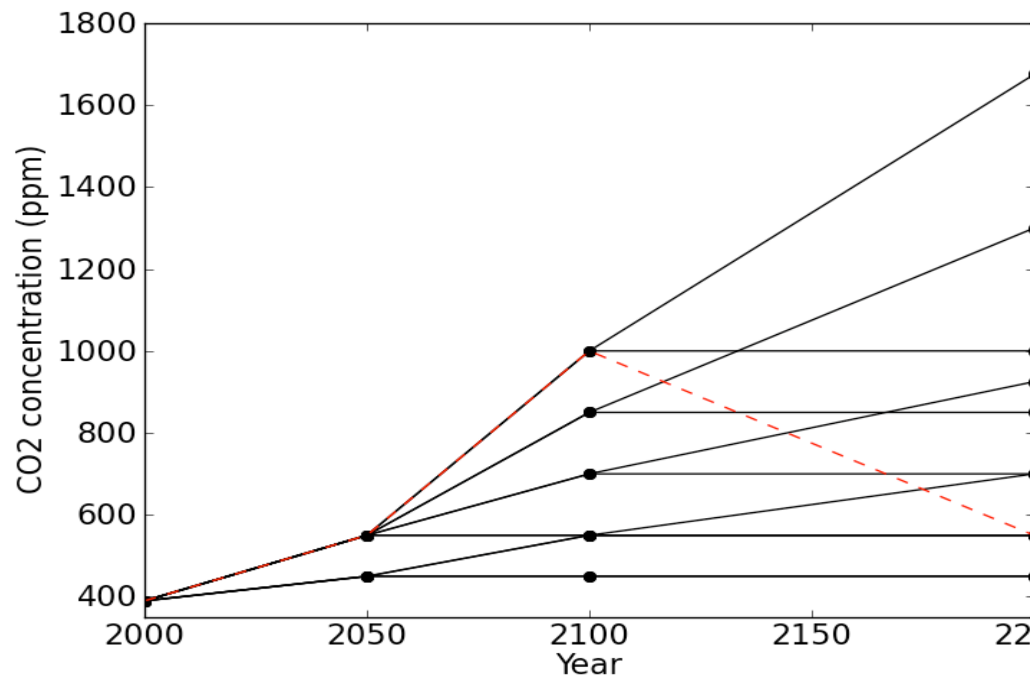


Will use this to performing initial tests of emulation techniques

Data from “Fast” and “Slow” warming scenarios used to emulate clima for “Medium” scenario. Compare approximate solution will “real” model solution

Future work: producing deliverable for community u

- Develop a larger library of CCSM3 runs
- Successfully applied for large computing allocation at NCAR for these runs



	Current (Steele @ Purdue)	Future (NCAR)
Scenario	3	12
Realizations	5	10
Years per run	~200	~300
Total model years	~3,000	~20,000
Computing resources	200,000 Sus	300,000 GAUs

Use library to develop a climate model emulator for use in climate changes impacts modeling